
بسم الله الرحمن الرحيم

Tanta University

Faculty of Engineering

Electrical Power and Machines Engineering Department

First Year – Second Term

(Electrical Power and Machines Engineering Department)

Course Title

Electrical Circuits (2)

EPM1203 (3+2)

Dr. Said M. Allam

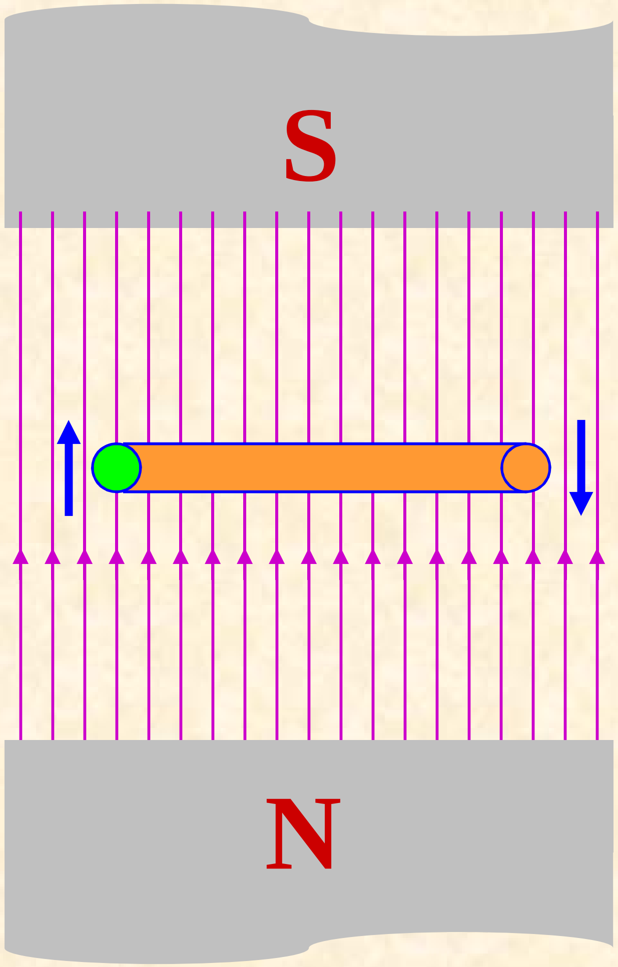
Part 2

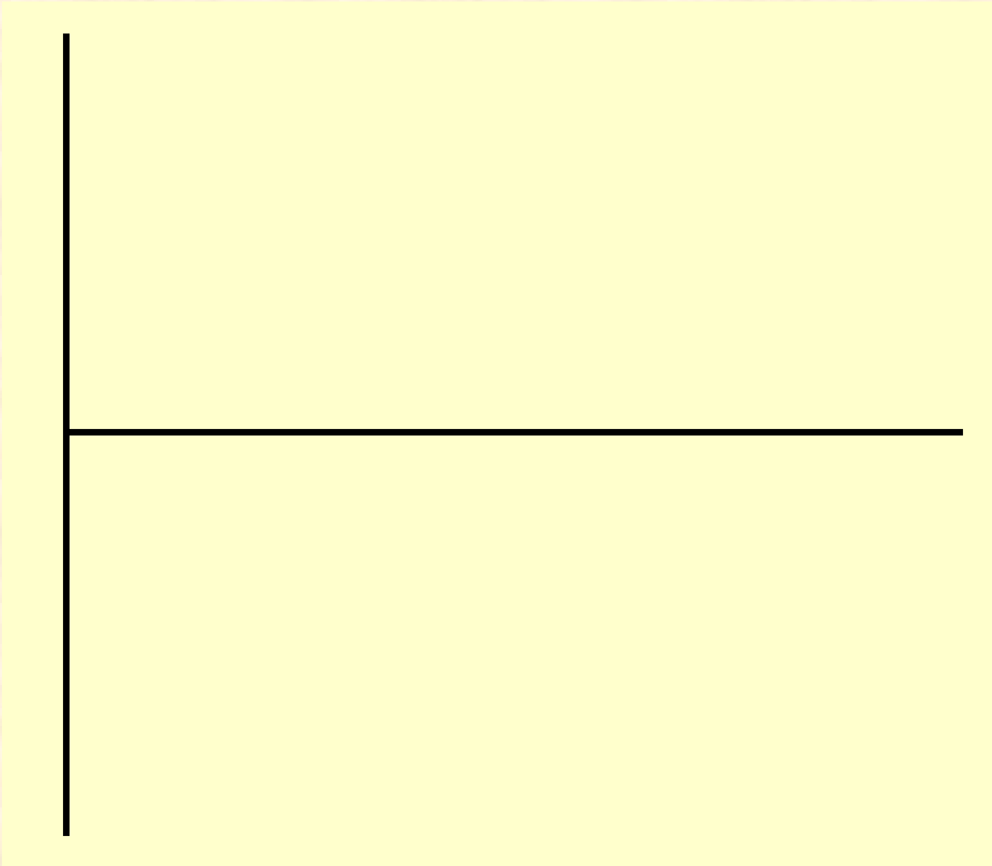
Balanced Three-Phase Circuits

Lecture Outlines

- Generating Single-Phase Voltage
- Generating three-phase Voltages
- Importance of Three-Phase System
- Three-Phase Generator
- Basic Three-Phase Circuit
- Y-Y Three-Phase System
- Solved Example on Y-Y System

Generating Single-Phase Voltage

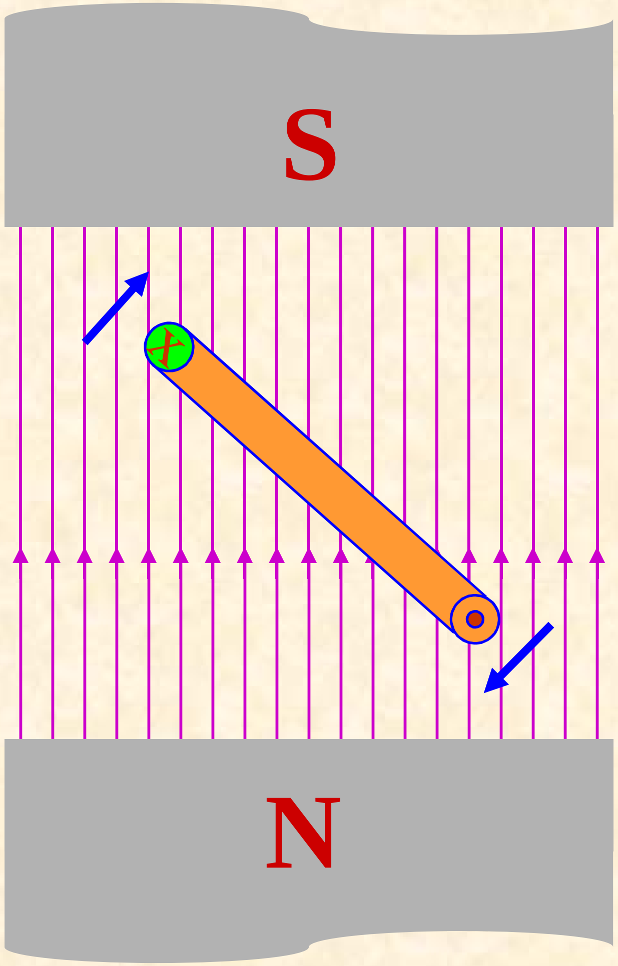


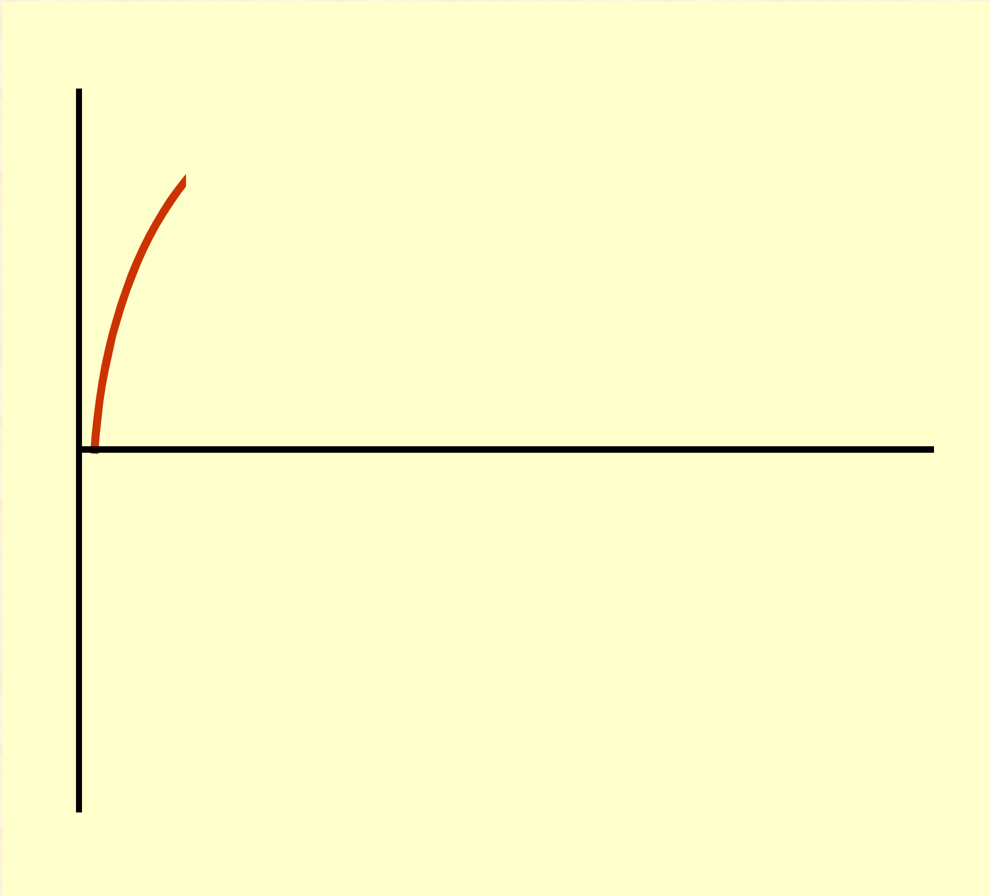


Motion is parallel to the flux

No voltage is induced

Generating Single-Phase Voltage

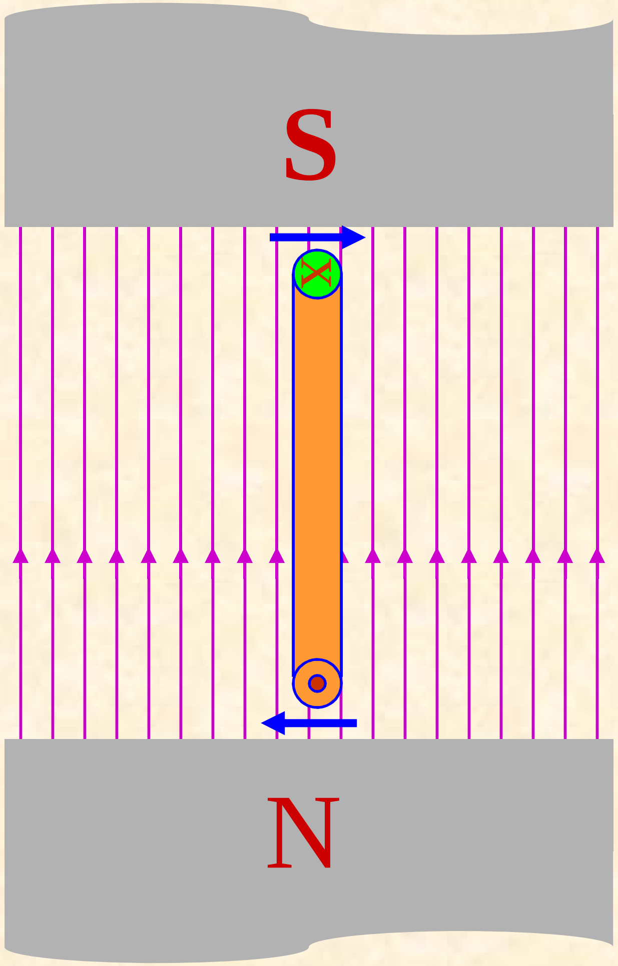


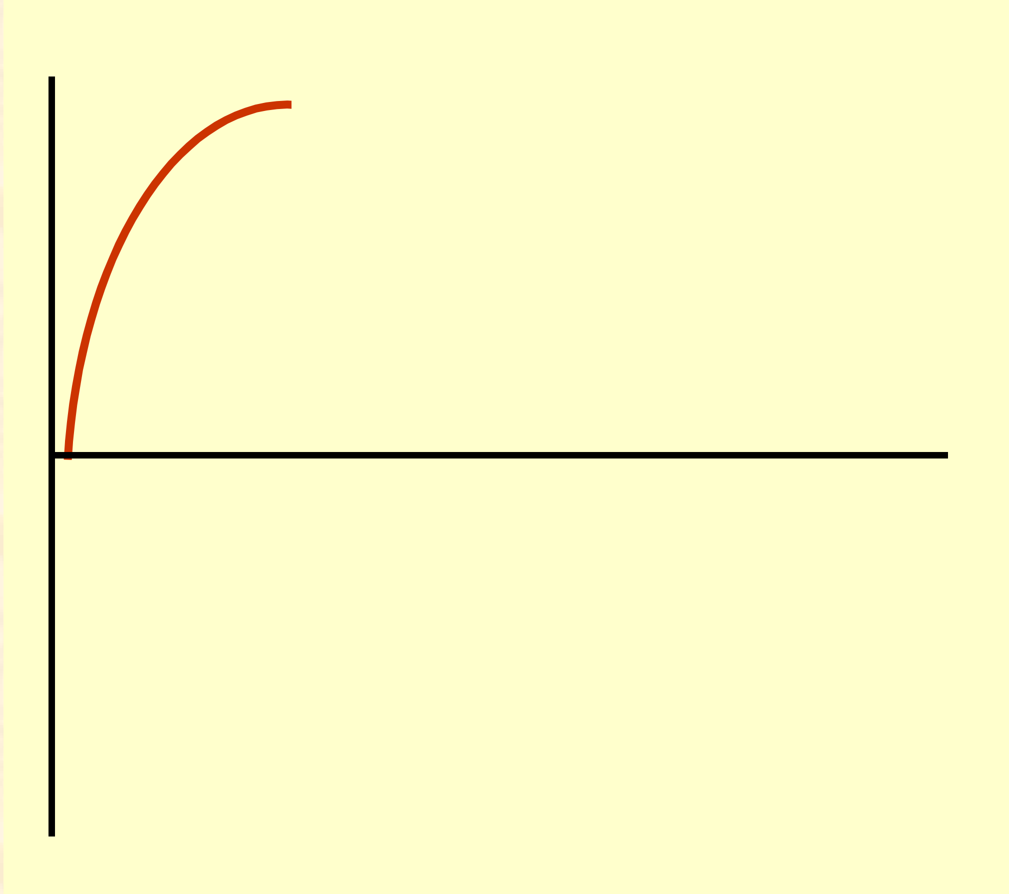


Motion is 45° to flux

Induced voltage is 0.707 of maximum

Generating Single-Phase Voltage

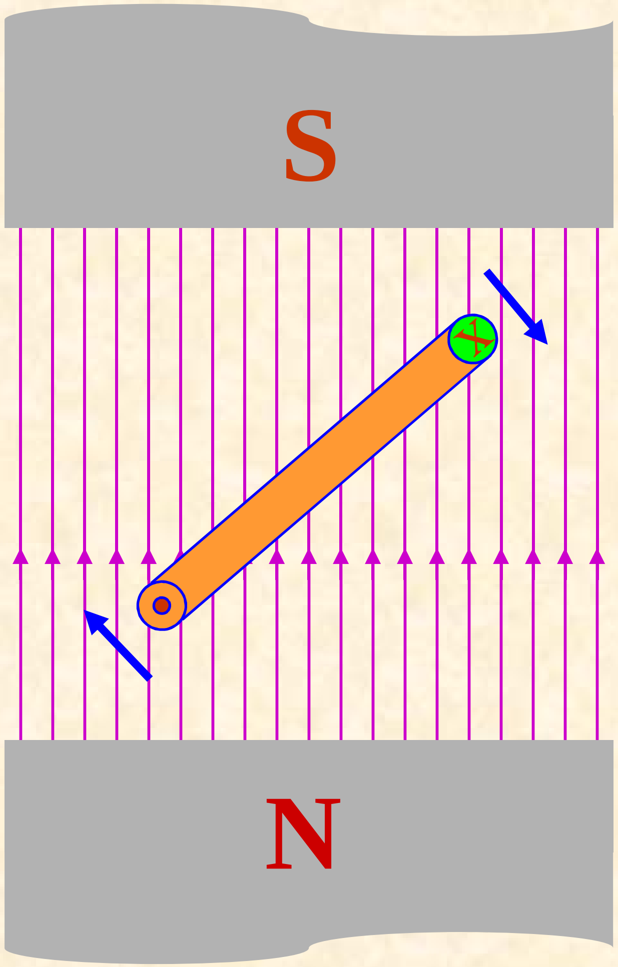


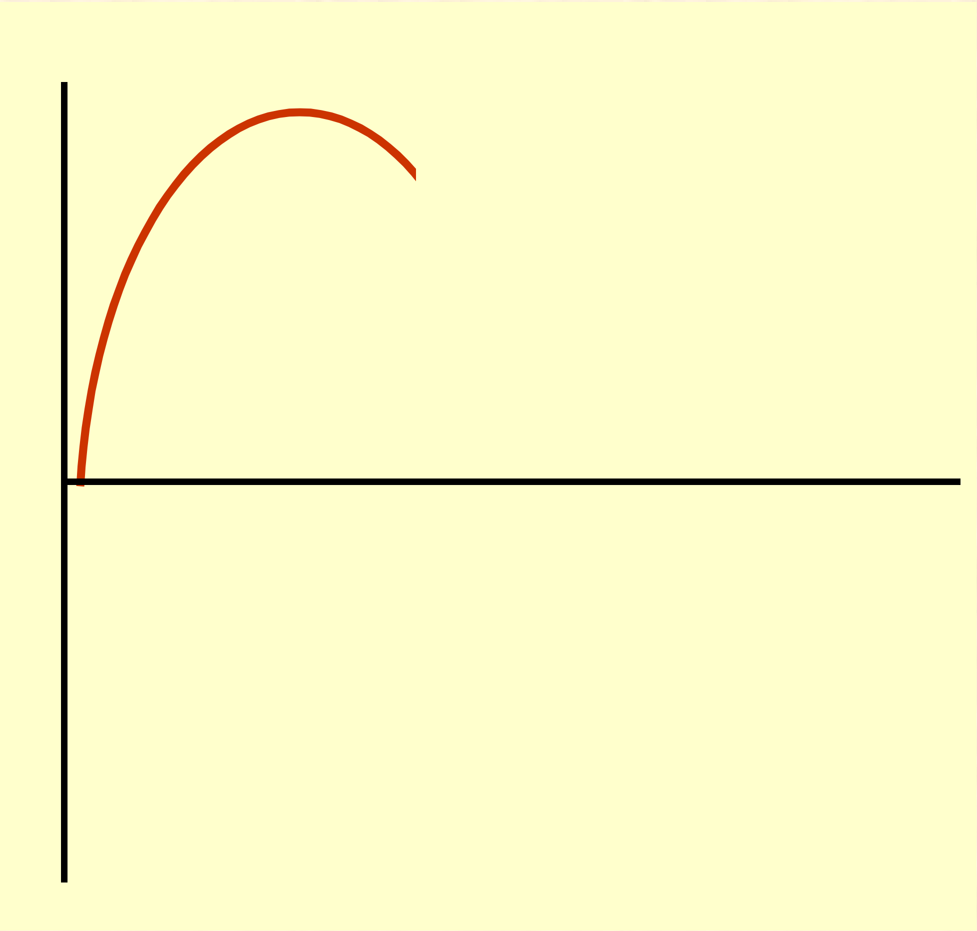


Motion is perpendicular to flux

Induced voltage is maximum

Generating Single-Phase Voltage

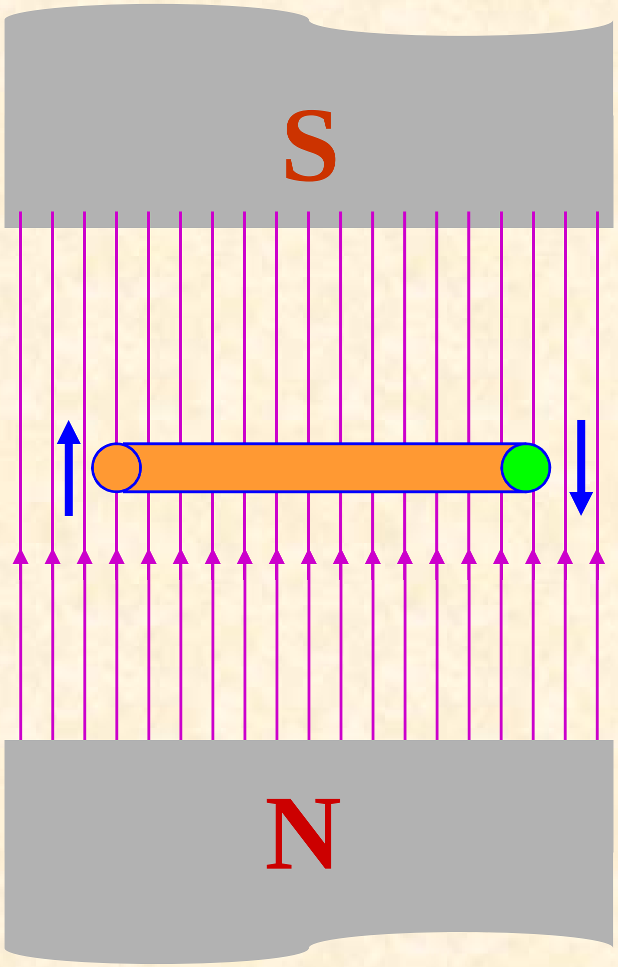


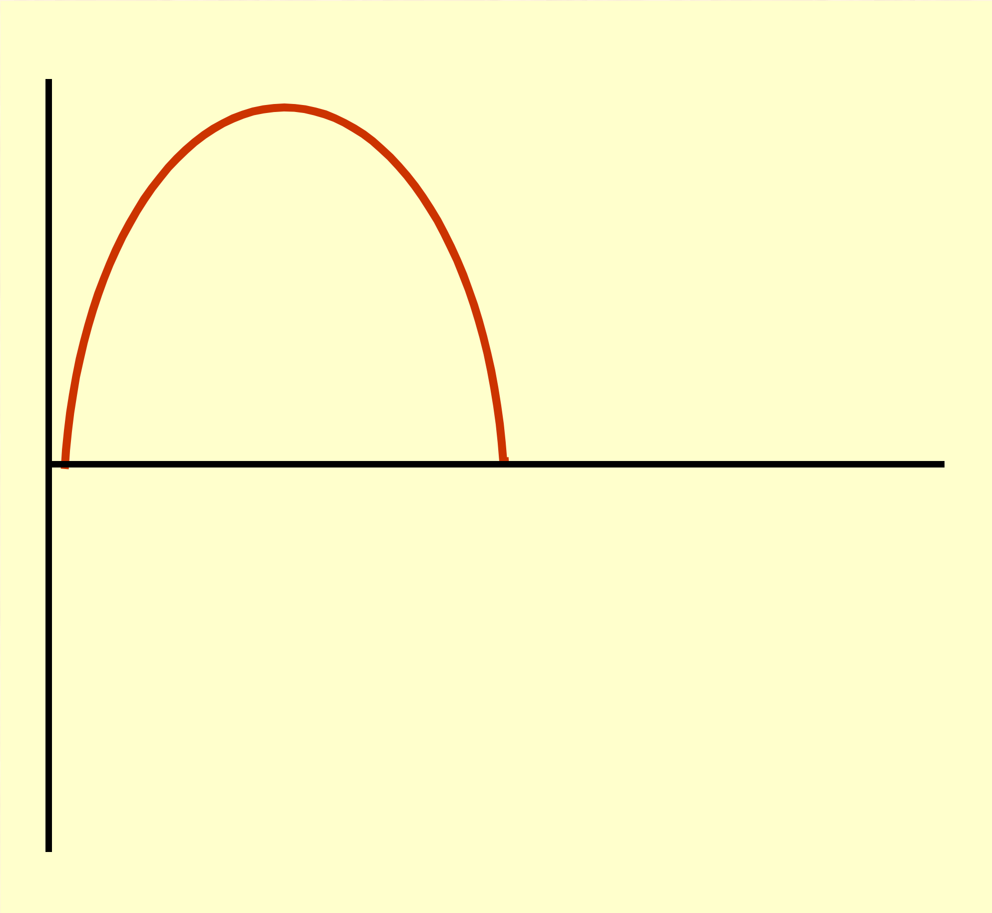


Motion is 45° to flux

Induced voltage is 0.707 of maximum

Generating Single-Phase Voltage

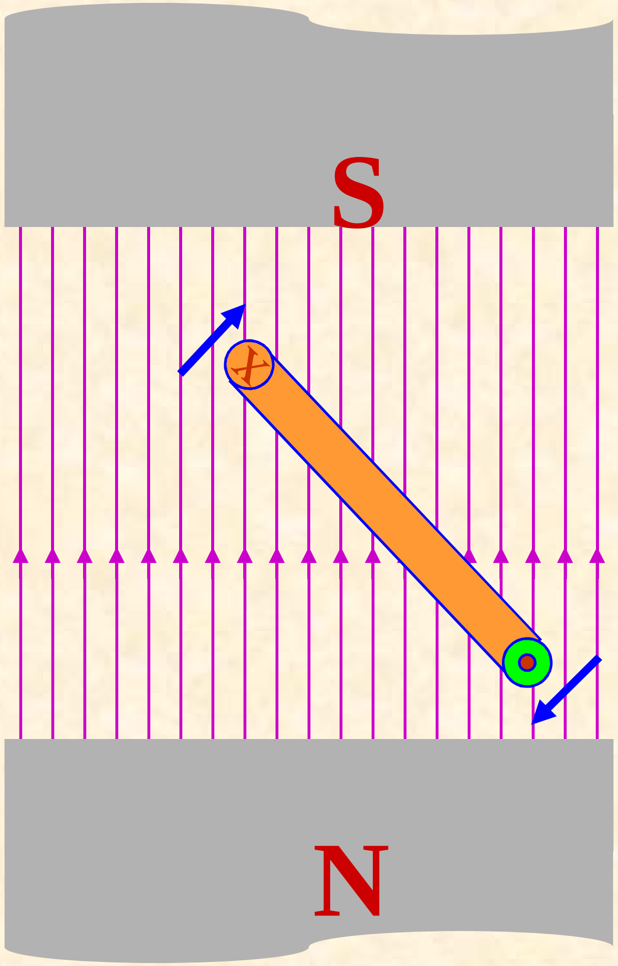


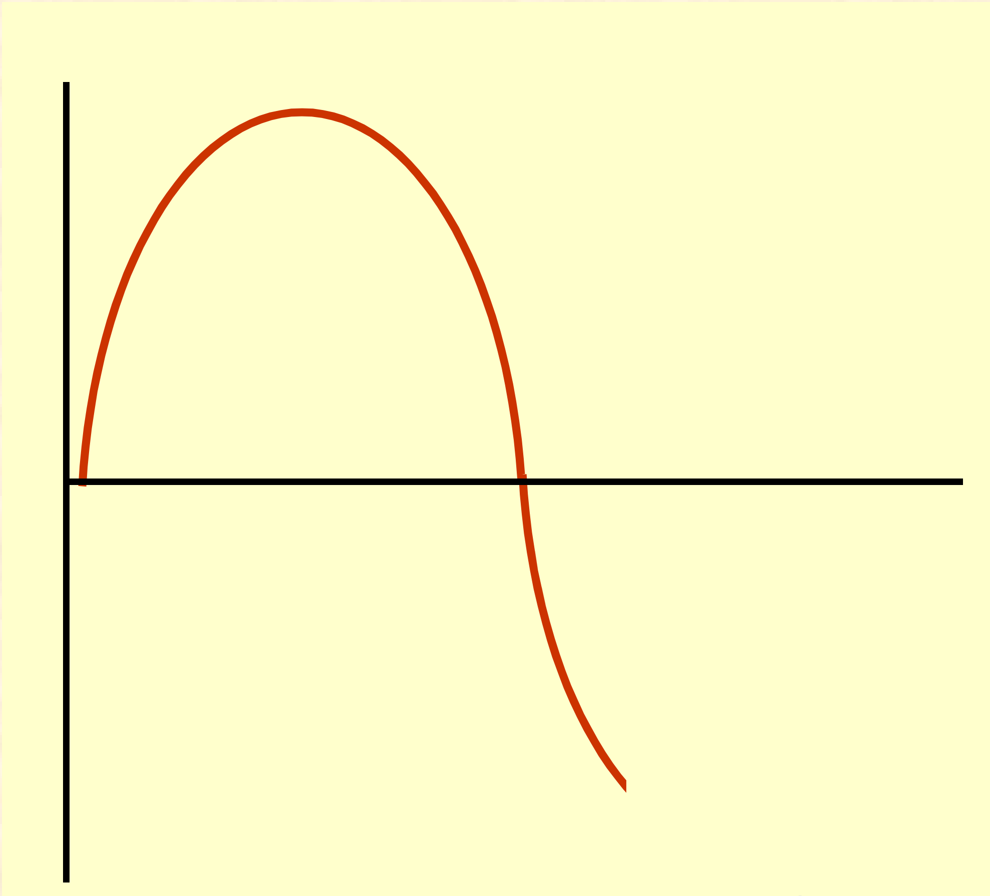


Motion is parallel to flux

No voltage is induced

Generating Single-Phase Voltage



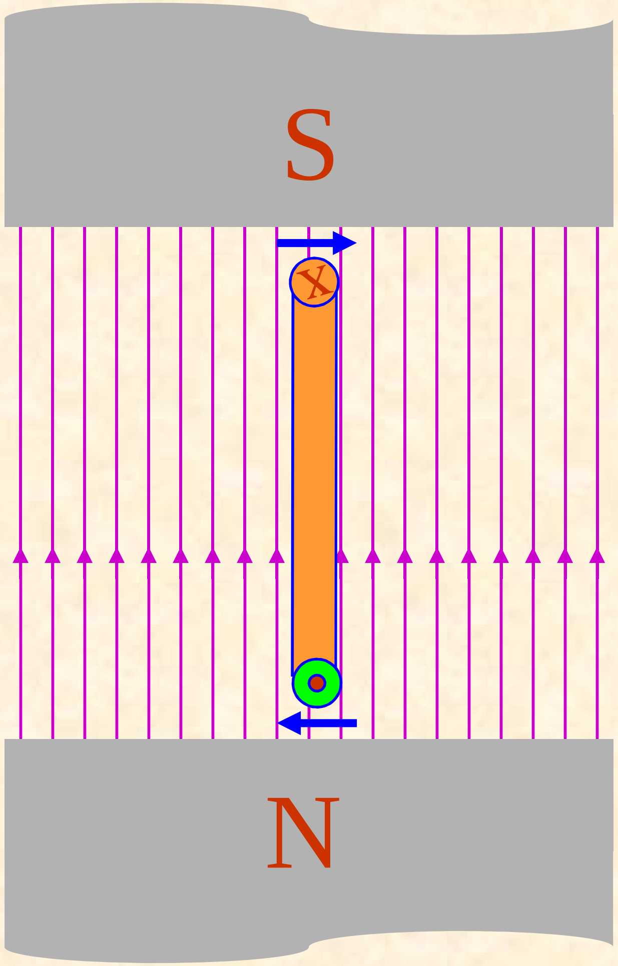


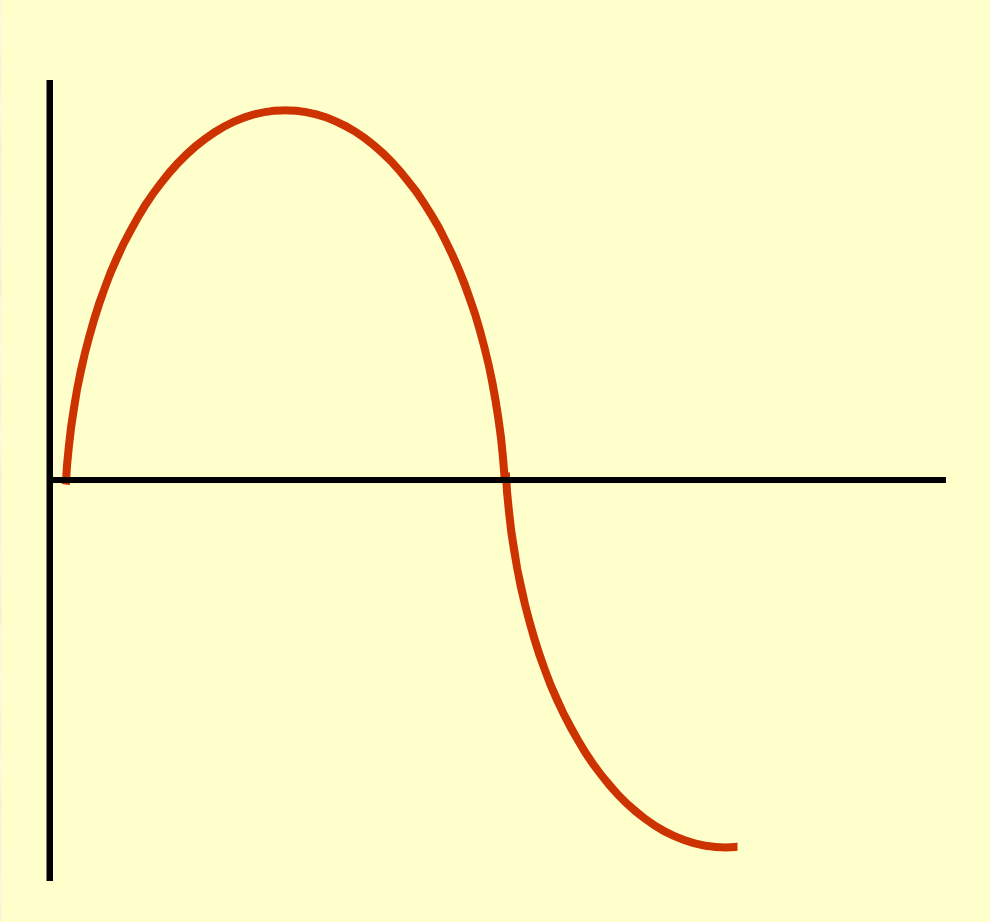
Notice current in the conductor has reversed.

Motion is 45° to flux

Induced voltage is 0.707 of maximum

Generating Single-Phase Voltage

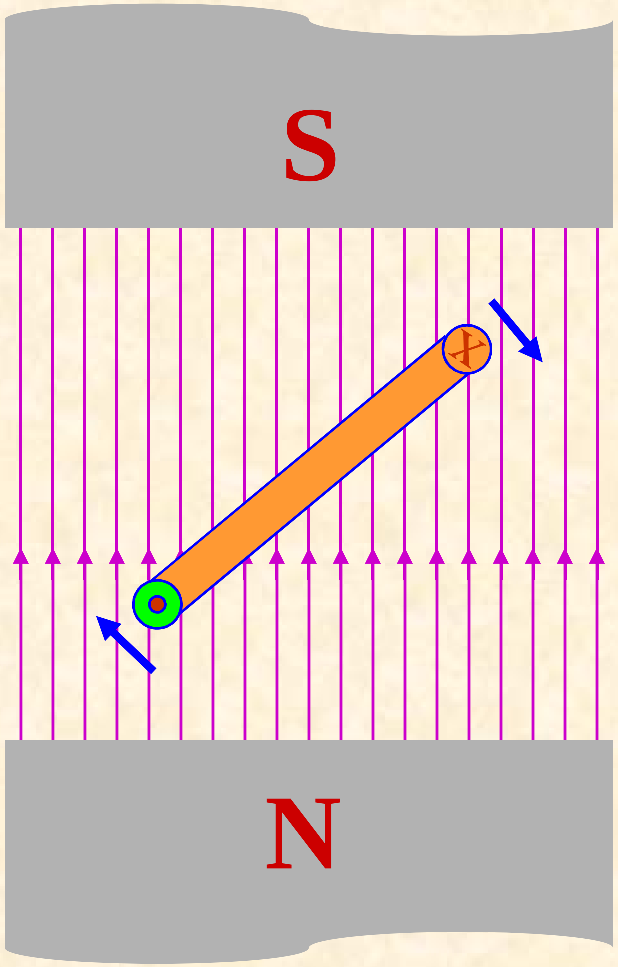


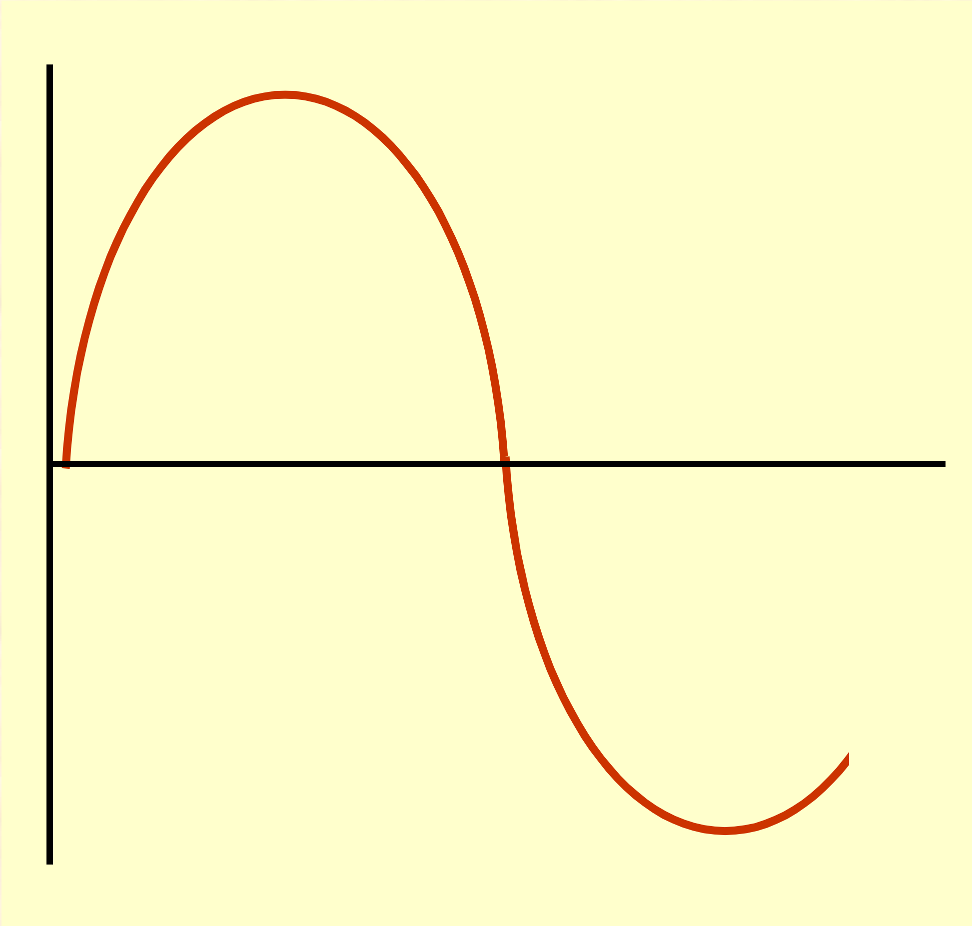


Motion is perpendicular to flux

Induced voltage is maximum

Generating Single-Phase Voltage

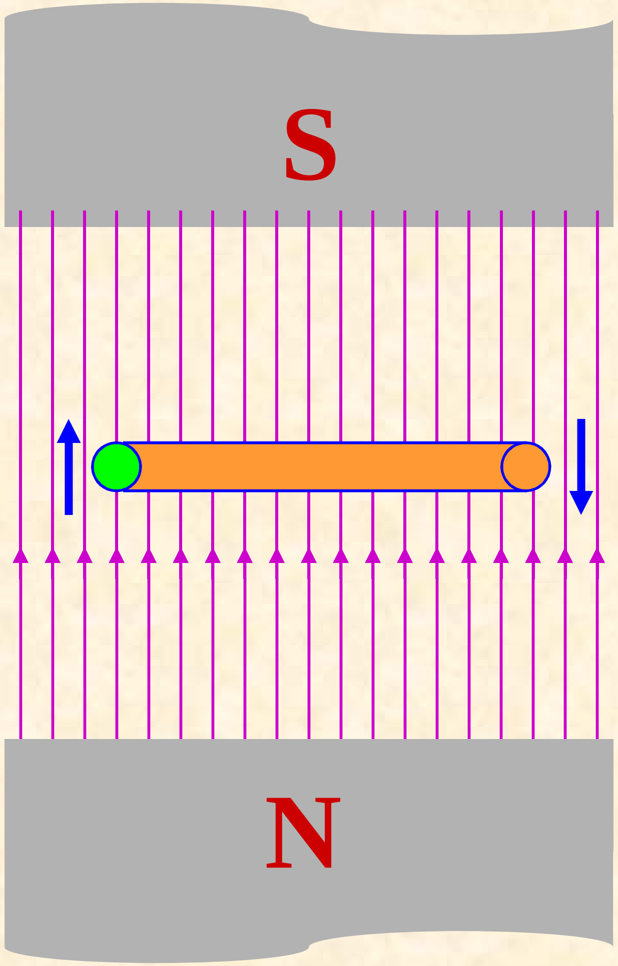


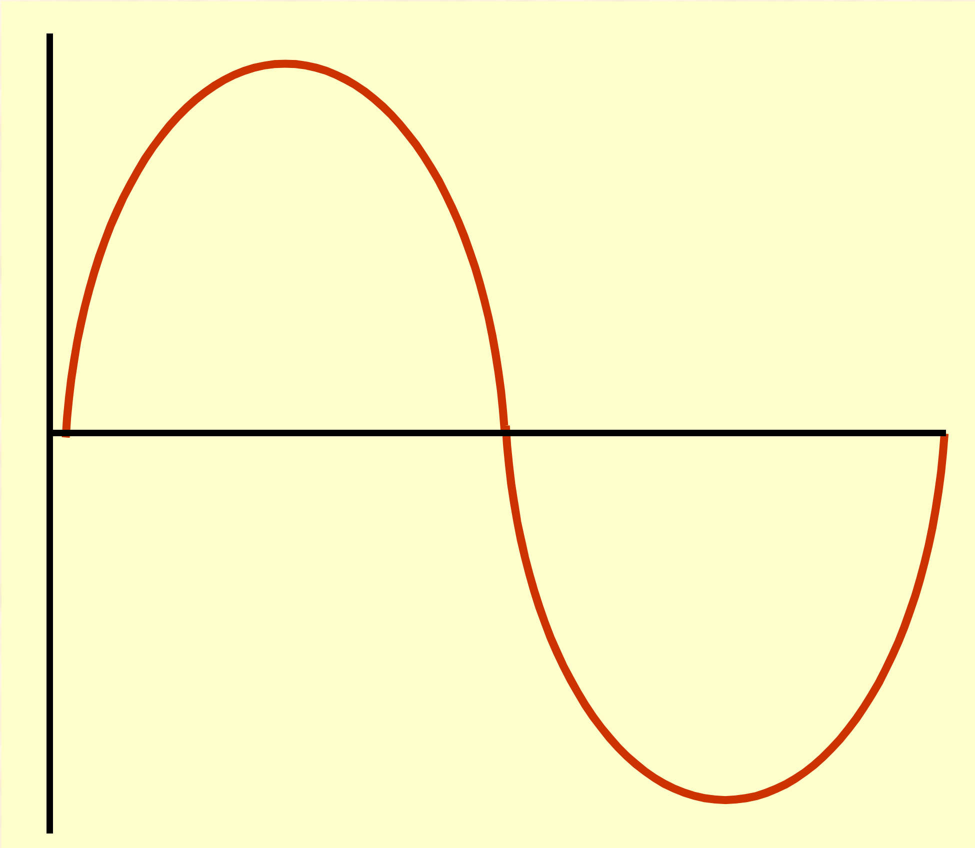


Motion is 45° to flux

Induced voltage is 0.707 of maximum

Generating Single-Phase Voltage



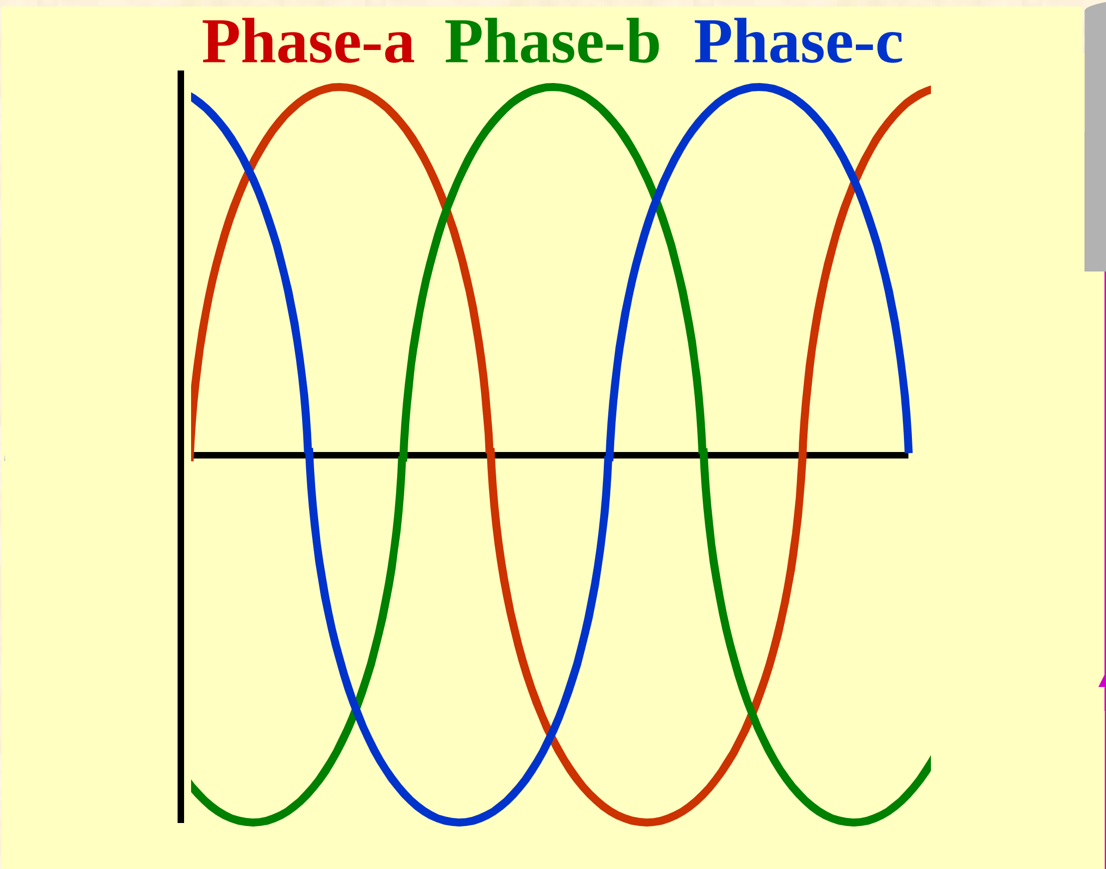


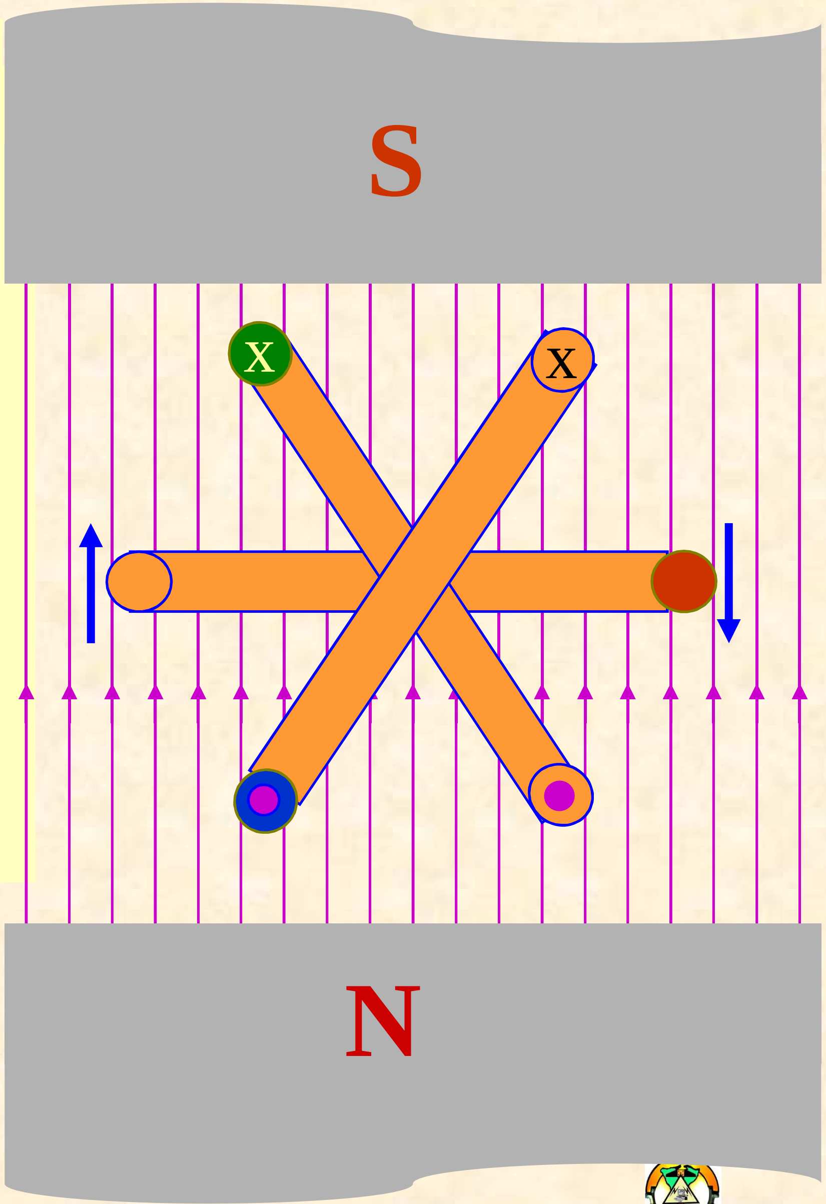
Motion is parallel to flux

No voltage is induced

Ready to produce another cycle

Generating Three-Phase Voltage



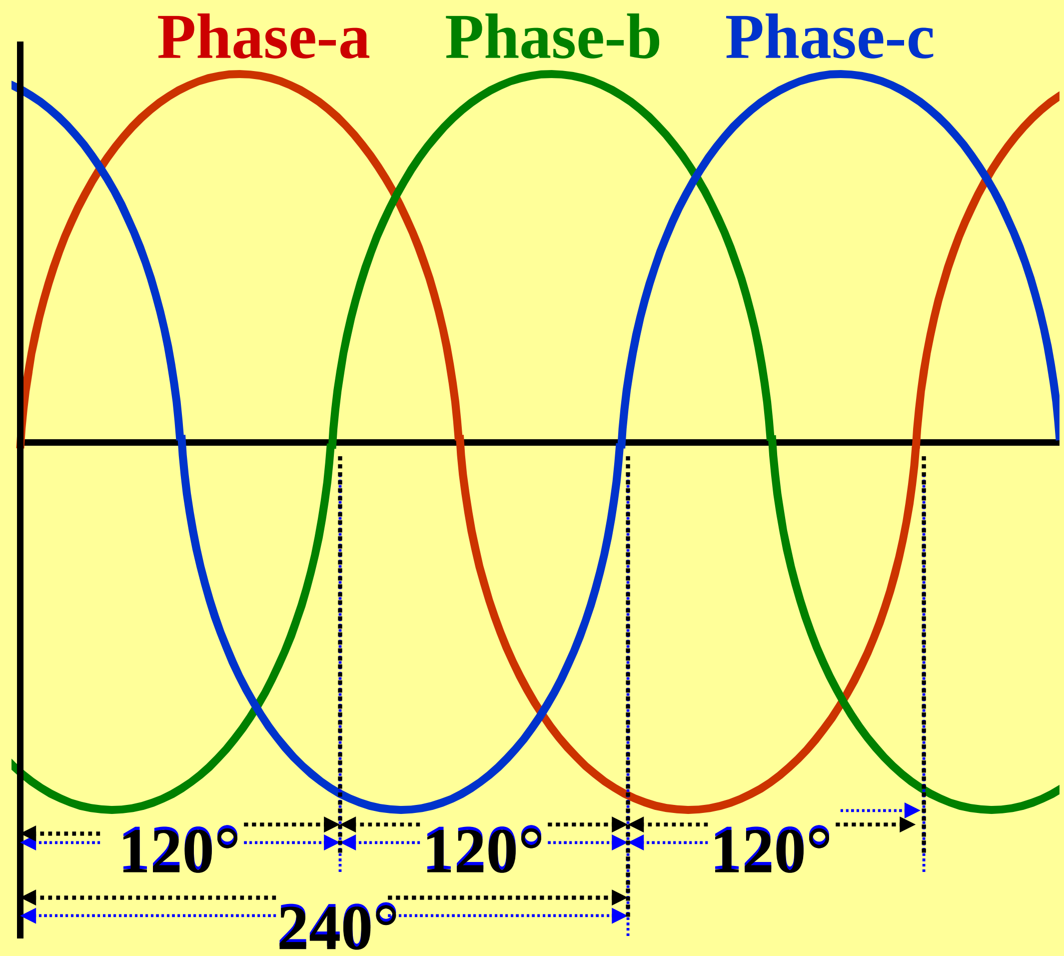


Phase-a is ready to go positive

Phase-b is going more negative

Phase-c is going less positive

Generating Three-Phase Voltage



Phase-b lags phase a by 120°

Phase-c lags phase a by 240°

Phase-b leads phase c by 120°

Phase-a leads phase c by 240°

Importance of Three-Phase System

- All electric power is generated and distributed in three phase
  - ✓ One phase, two phase, can be taken from three phase system rather than generated independently
  - ✓ The instantaneous power in a 3ϕ system can be constant (not pulsating)
  - ✓ High power motors prefer a steady torque especially one created by a rotating magnetic field
  - ✓ Three phase system is more economical than the single phase
  - ✓ The amount of wire required for a three phase system is less than required for an equivalent single phase system

Three-Phase Generator

- The generator consists of a rotating magnet (rotor) surrounded by a stationary winding (stator)

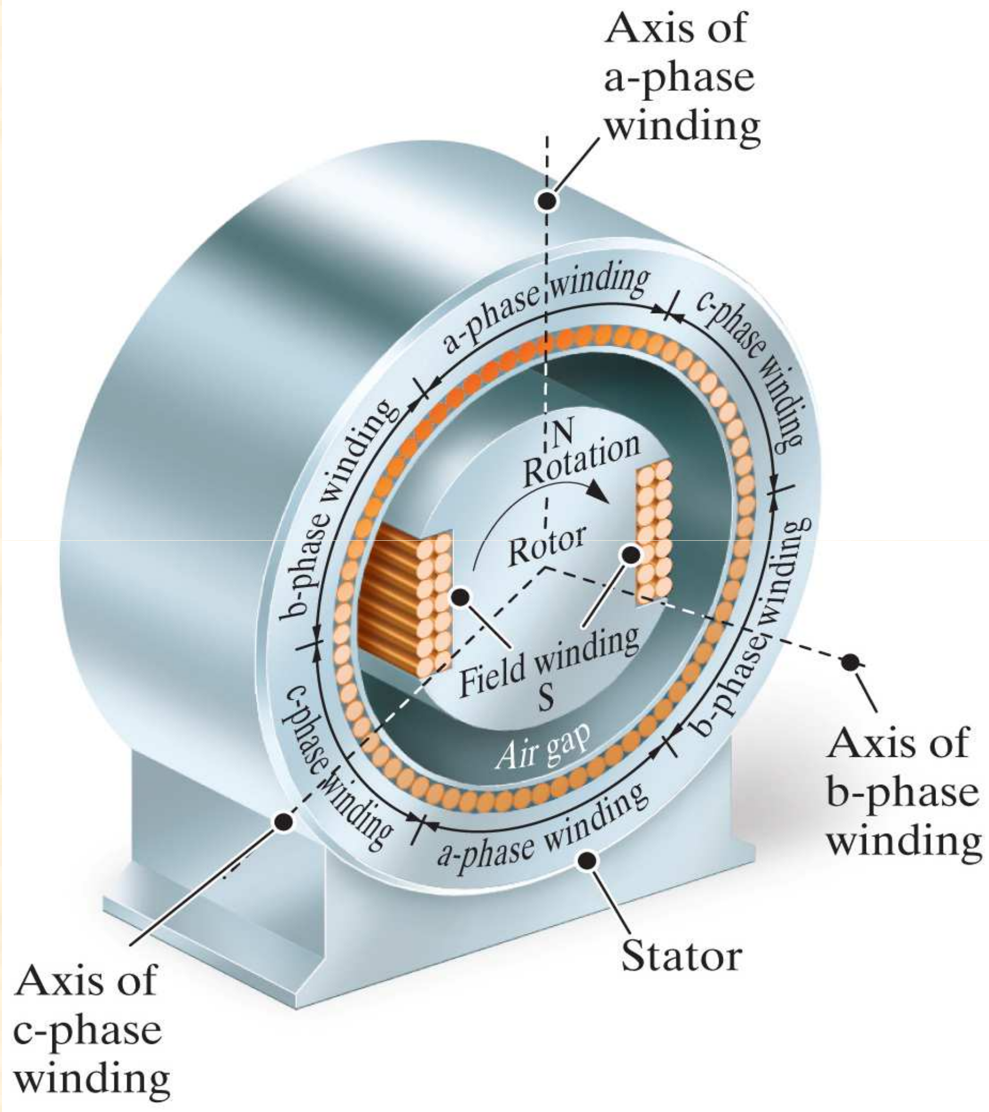
- Three separate windings or coils with terminals a-a’, b-b’, and c-c’ are physically placed 120° apart around the stator

- As the rotor rotates, its magnetic field cuts the flux from the three coils and induces voltages in the coils

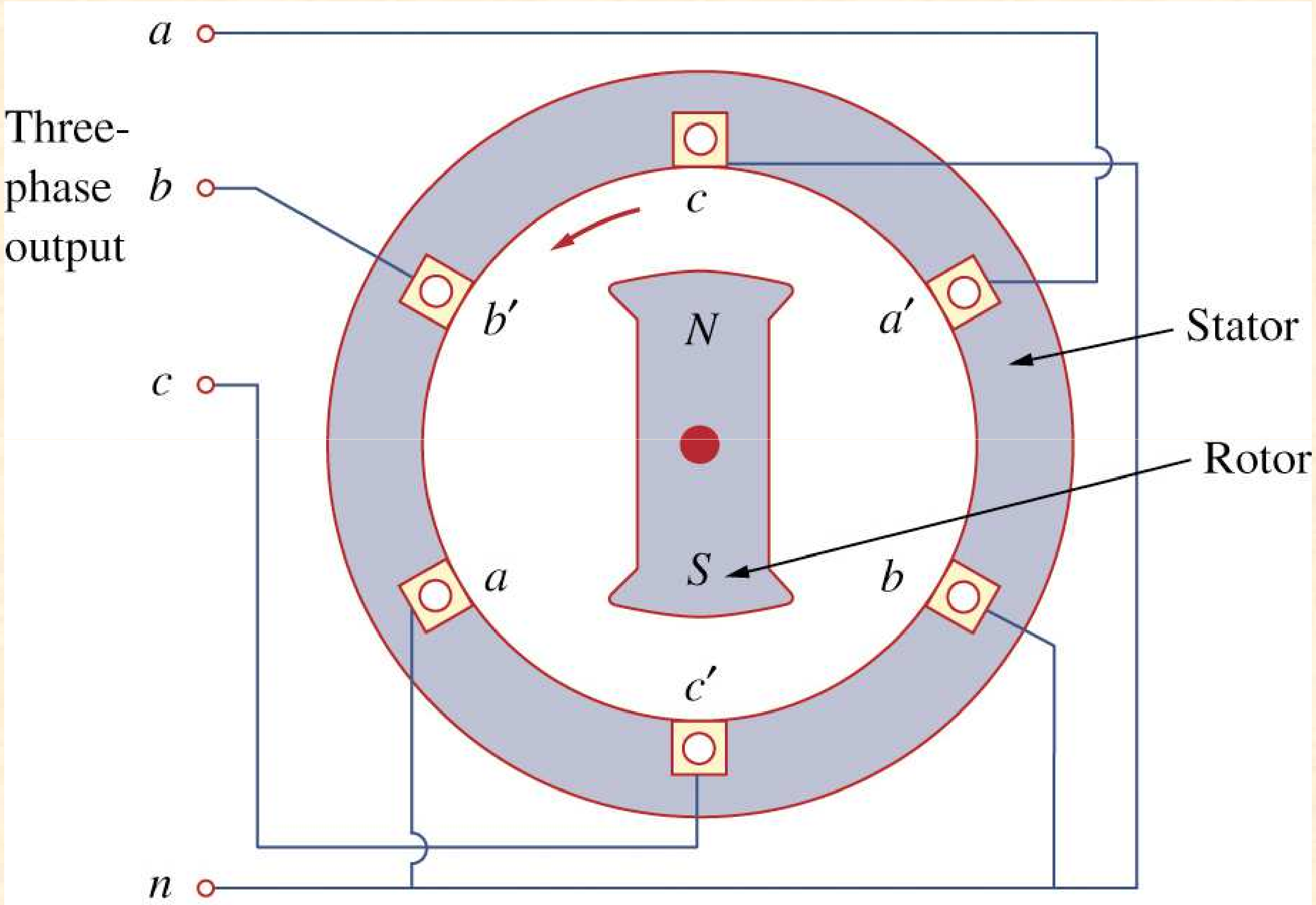
- The induced voltage have equal magnitude but out of phase by 120°

Three-Phase Generator

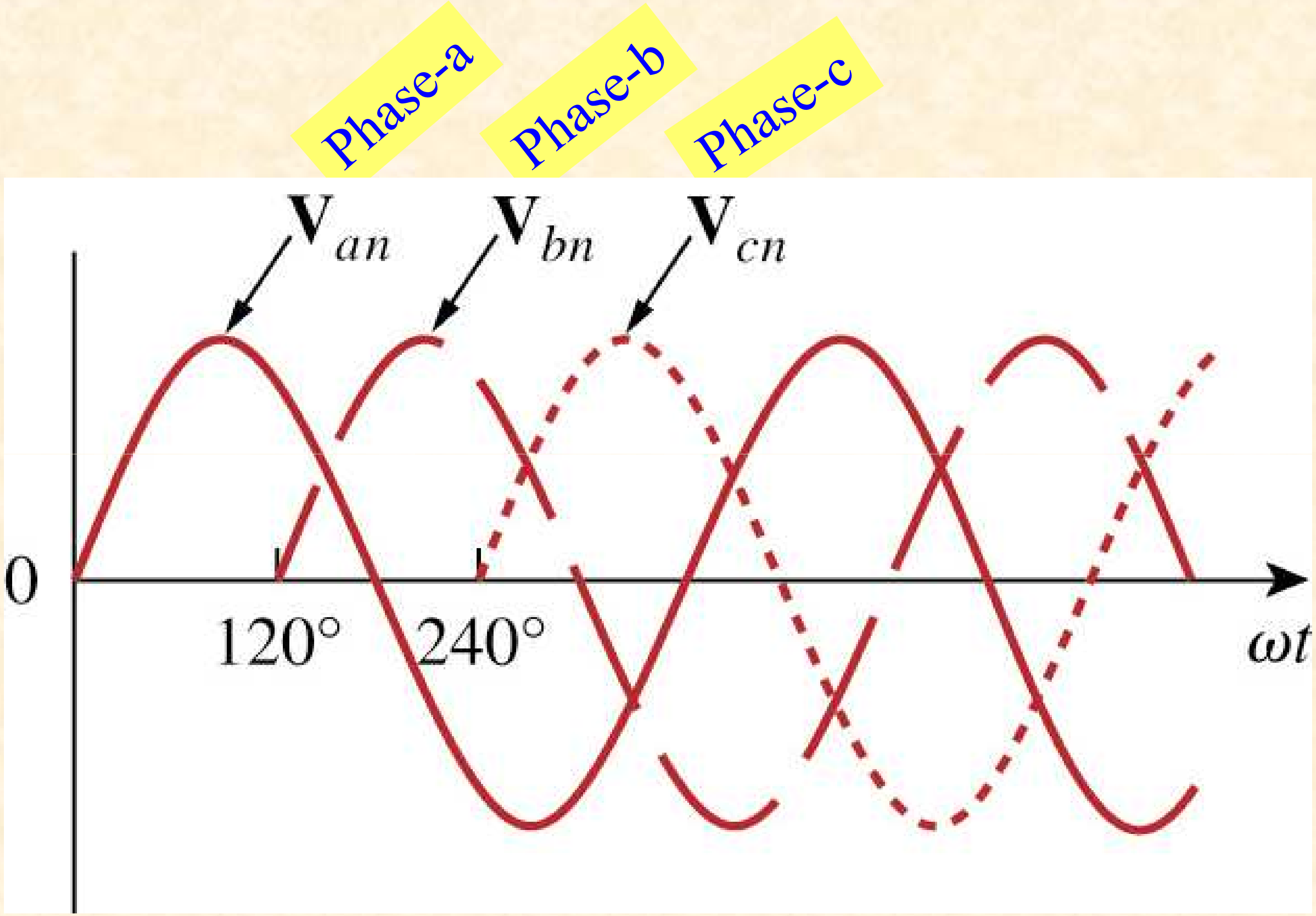
- ✓ 2-pole (North-South) rotor turned by a "prime mover"
- ✓ Sinusoidal voltages are induced in each stator winding



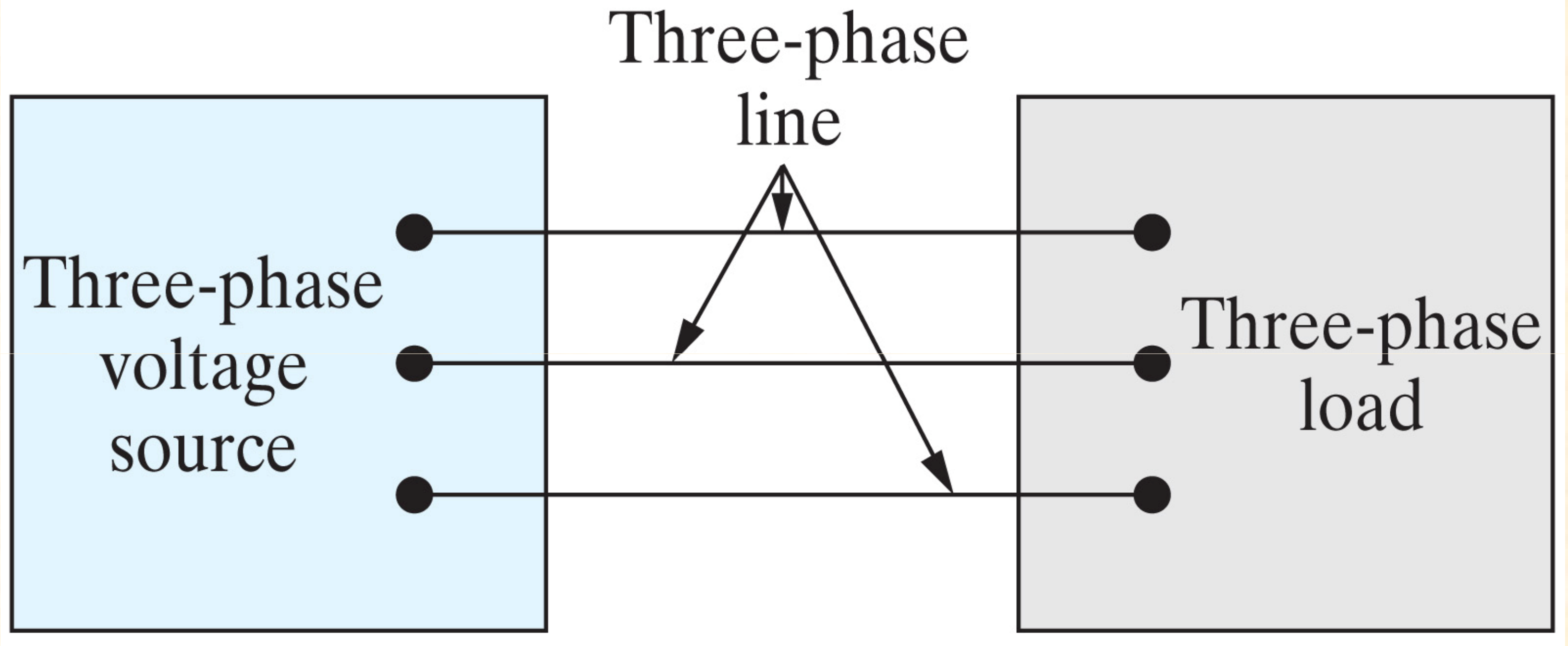
Three-Phase Generator



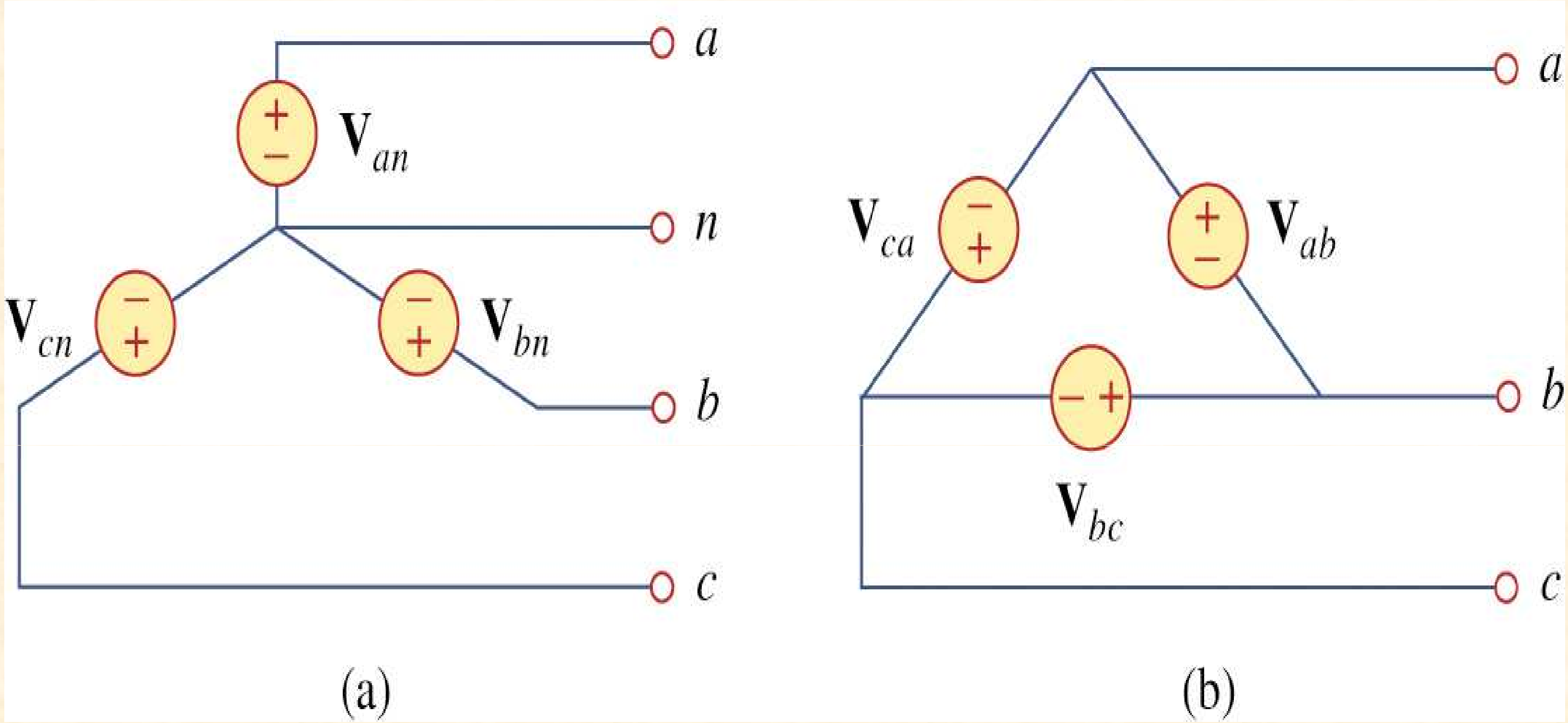
Three-Phase Voltages



Basic Three-Phase Circuit



Three-Phase Voltages Sources

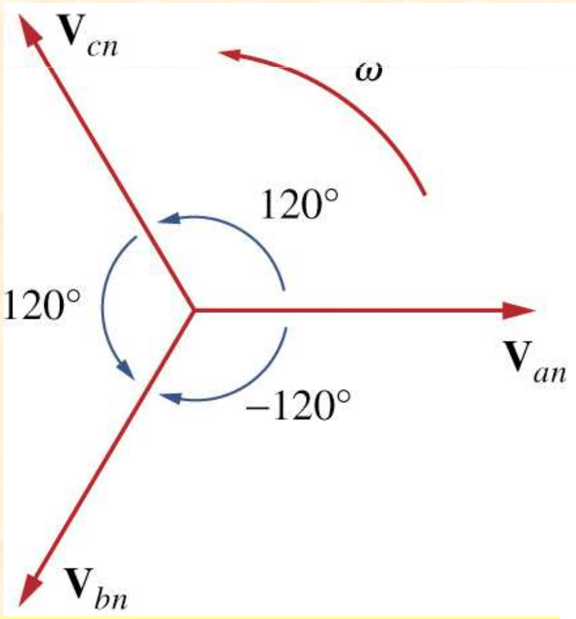


Y-connected Source

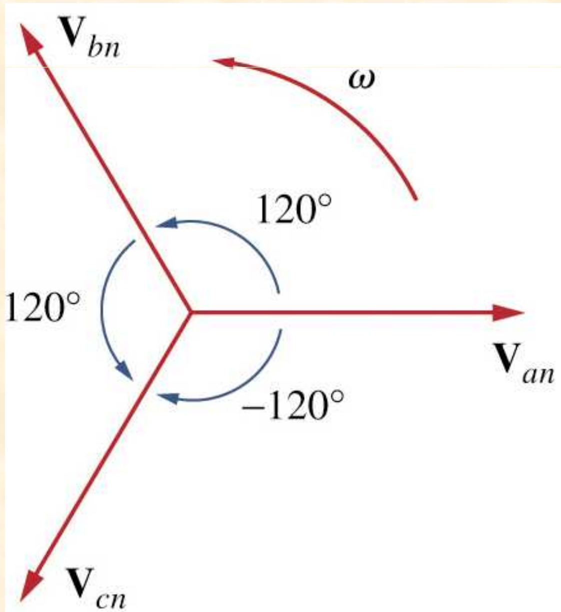
Δ-connected Source

Balanced Three-Phase Voltages Sources

- Balanced phase voltages are equal in magnitude and are out of phase with one another by 120 degrees
- Phase voltages sum up to zero **($V_{an} + V_{bn} + V_{cn} = 0$)**
- There are two possible combinations:



abc or (+) sequence



acb or (–) sequence

Balanced Three-Phase Voltages

$$v_{an}(t) = V_M \cos(\omega t)$$
$$v_{bn}(t) = V_M \cos(\omega t - 120°)$$
$$v_{cn}(t) = V_M \cos(\omega t - 240°) = V_M \cos(\omega t + 120°)$$

$$V_{an} = V_M \angle 0°$$
$$V_{bn} = V_M \angle -120°$$
$$V_{cn} = V_M \angle +120°$$

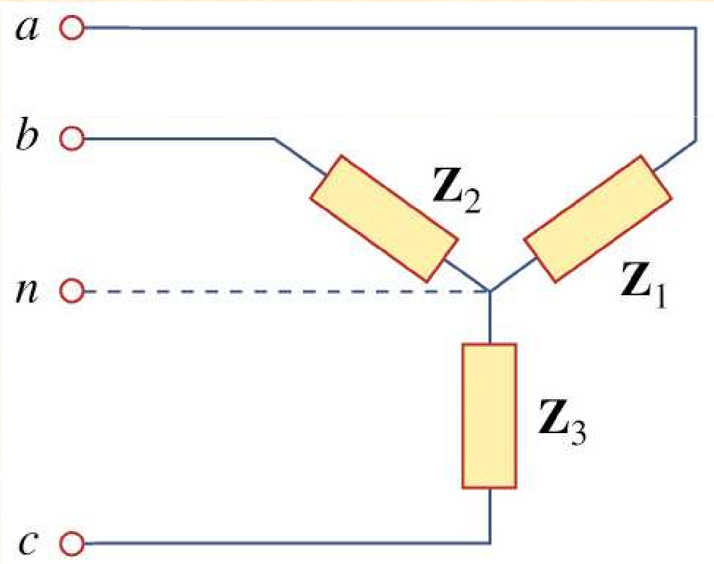
POSITIVE SEQUENCE

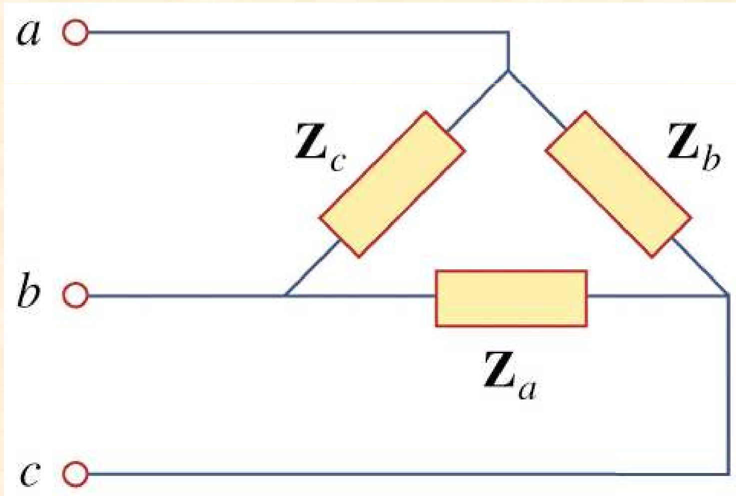
$$V_{an} = V_M \angle 0°$$
$$V_{bn} = V_M \angle +120°$$
$$V_{cn} = V_M \angle -120°$$

NEGATIVE SEQUENCE

Balanced Three-Phase Load Configurations

➢A balanced three-phase load is one in which the phase impedances are equal in magnitude and in phase





Y-connected Load

Δ-connected Load

Source-Load Connection

SOURCE	LOAD	CONNECTION
Wye	Wye	Y-Y
Wye	Delta	Y-Δ
Delta	Delta	Δ- Δ
Delta	Wye	Δ-Y

Three-Phase Quantities

QUANTITY	SYMBOL
Phase current	I_ϕ
Line current	I_L
Phase voltage	V_ϕ
Line voltage	V_L

Phase Voltages and Line Voltages & Currents

- Phase voltage, (V_ϕ) is measured between the neutral and any line: line to neutral voltage
- Line voltage, (V_L) is measured between any two of the three lines: line to line voltage
- Line current, (I_L) is the current in each line of the source or load
- Phase current, (I_ϕ) is the current in each phase of the source or load

Balanced Y- Connected Voltage Source

✓ Line currents equal phase Currents

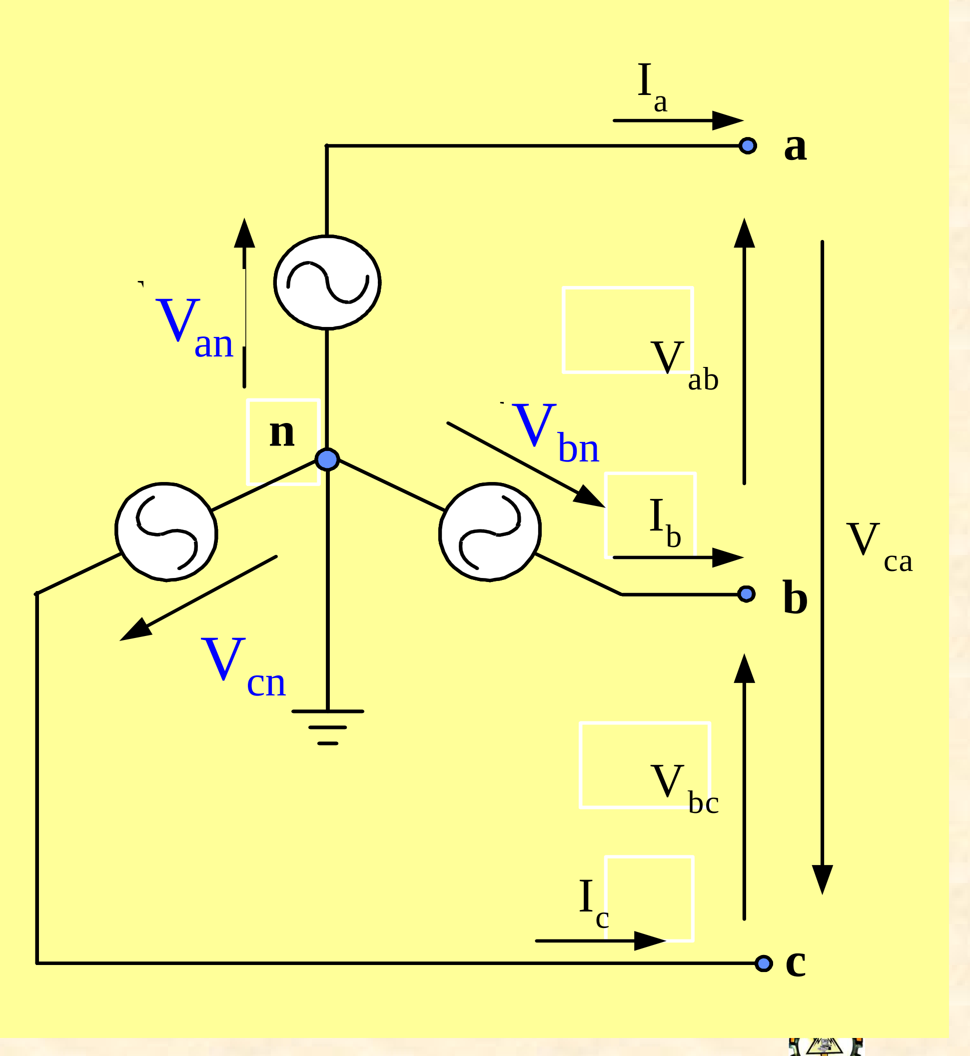
$$\boxed{I_L = I_\varphi}$$

✓ Phase voltages are

(V_{an}, V_{bn}, V_{cn})

✓ Line voltages are

(V_{ab}, V_{bc}, V_{ca})



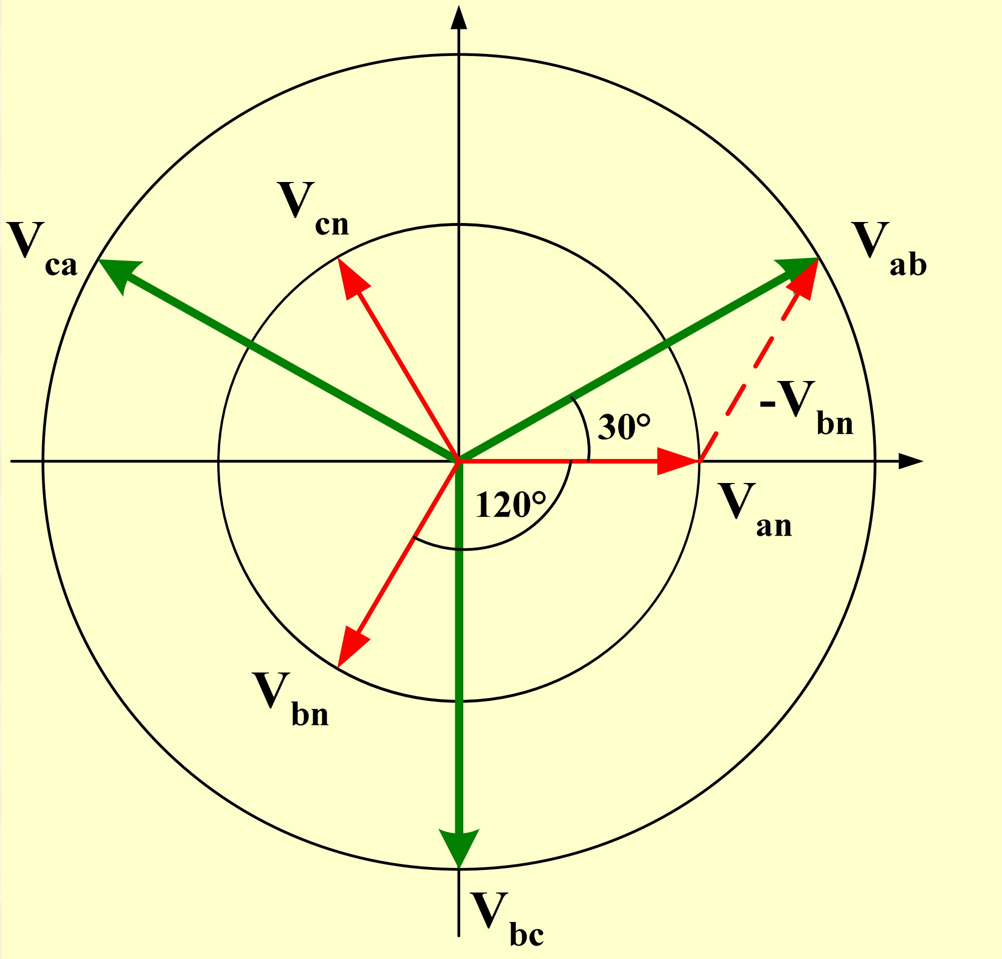
Phase Diagram of Line and Phase Voltages (+ve Sequence)

- **PHASE VOLTAGE**

$$V_{an} = V_M \angle 0^\circ \quad \text{volt}$$
$$V_{bn} = V_M \angle -120^\circ \quad \text{volt}$$
$$V_{cn} = V_M \angle 120^\circ \quad \text{volt}$$

- **LINE VOLTAGE**

$$V_{ab} = V_{an} - V_{bn}$$
$$V_{bc} = V_{bn} - V_{cn}$$
$$V_{ca} = V_{cn} - V_{an}$$



Relation Between Line and Phase Voltages (+ve Sequence)

LINE VOLTAGE (V_L)

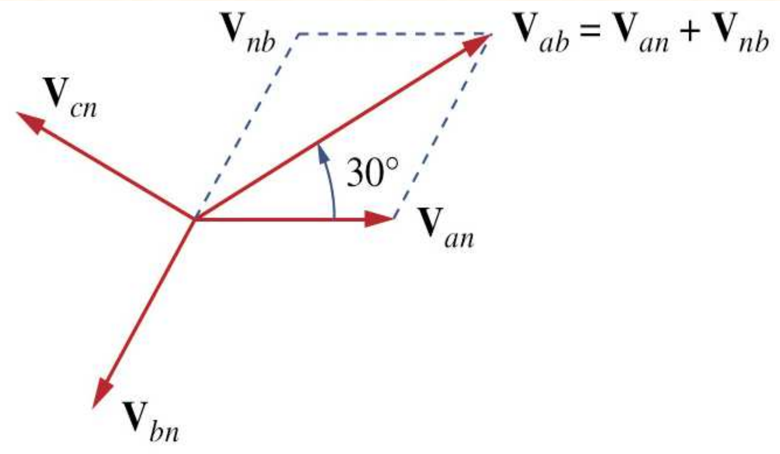
$$\begin{cases} V_{ab} = \sqrt{3}\, V_M \angle 30^\circ \quad \text{volt} \\ V_{bc} = \sqrt{3}\, V_M \angle -90^\circ \ \text{volt} \\ V_{ca} = \sqrt{3}\, V_M \angle 150^\circ \quad \text{volt} \end{cases}$$

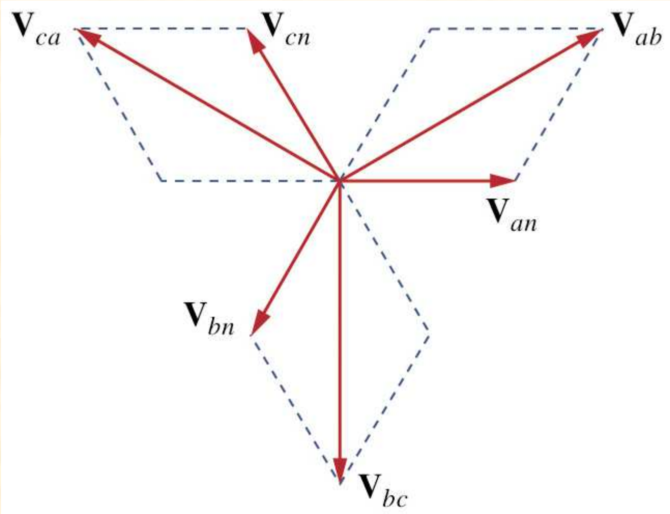
$$\left| V_L \right| = \sqrt{3} \left| V_\phi \right|$$

$$\angle V_L = \angle V_\phi + 30^\circ$$

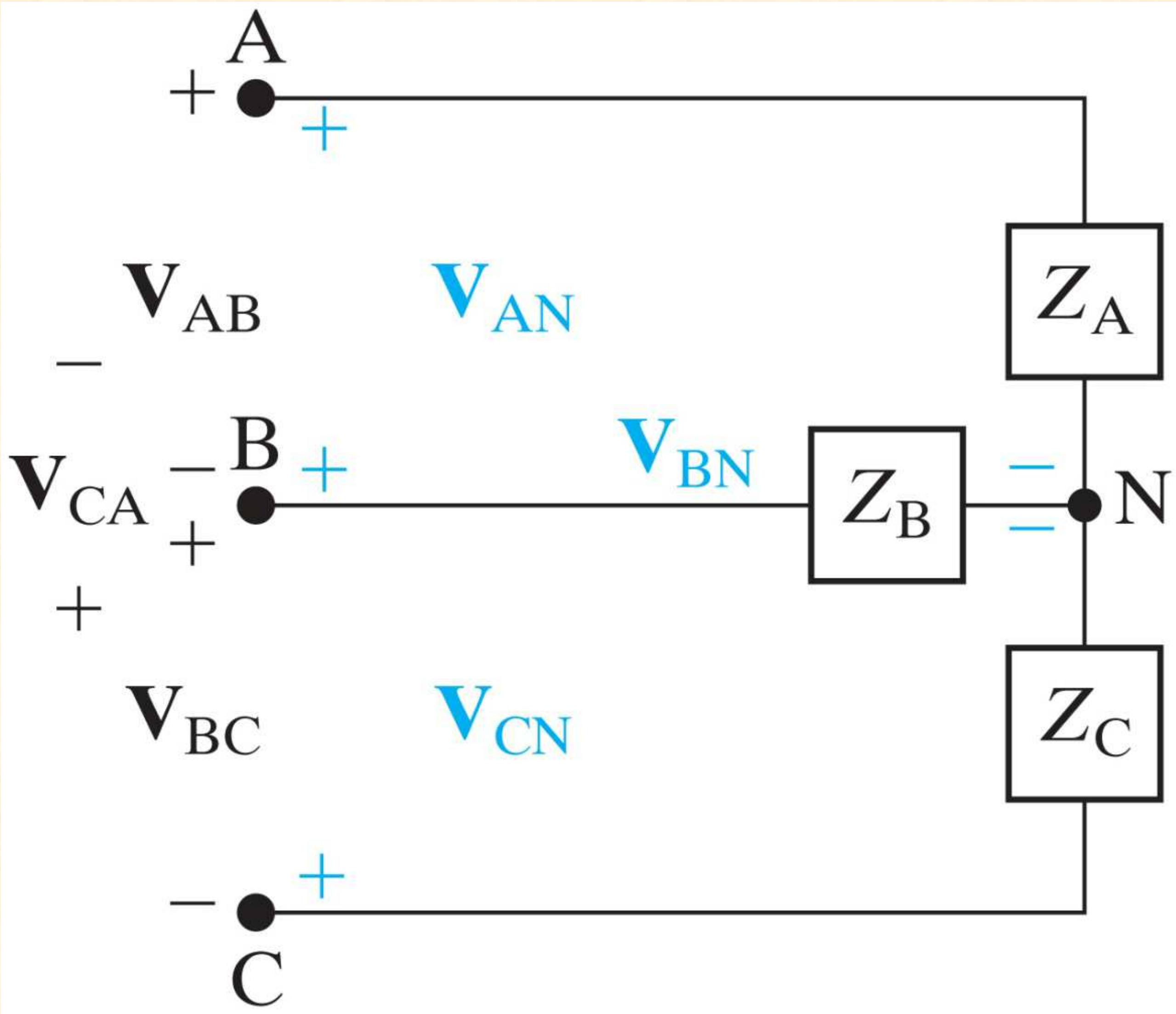
Conclusions for Balanced Y-connected Voltage Source

- Balanced line voltages are equal in magnitude and are out of phase with one another by 120 degrees
- Line voltages sum up to zero **($V_{ab} + V_{bc} + V_{ca} = 0$)**
- The magnitude of line voltages is $\sqrt{3}$ times the magnitude of the phase voltages
- Line Voltages <u>lead</u> their corresponding phase voltages by 30 degrees (for +ve sequence)

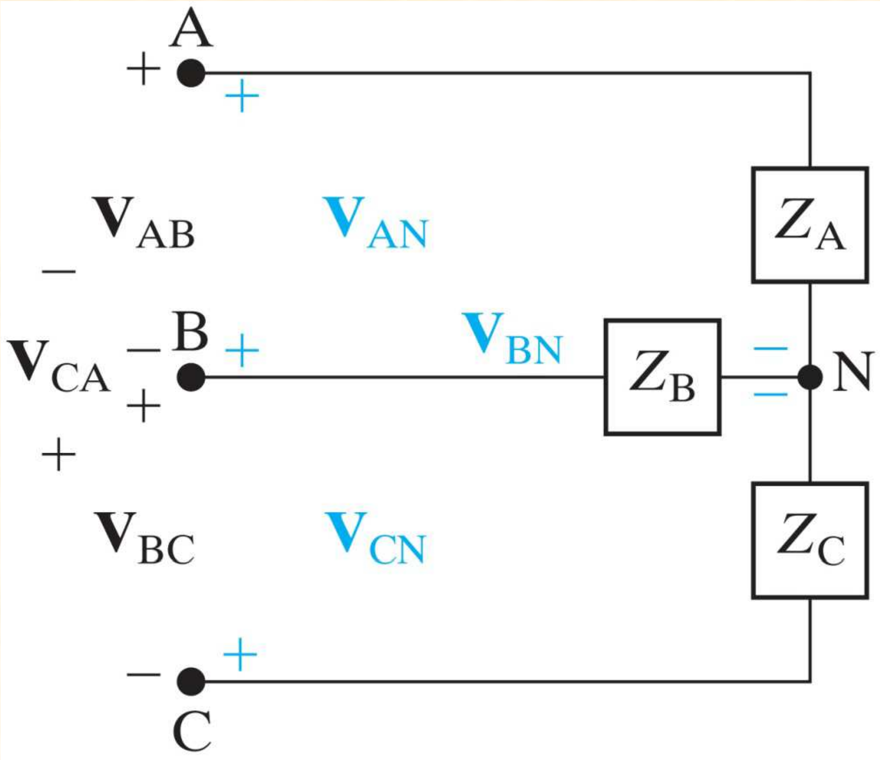




Balanced Y-connected Load



Balanced Y-connected Load



$$V_{AB} = V_{AN} - V_{BN}$$

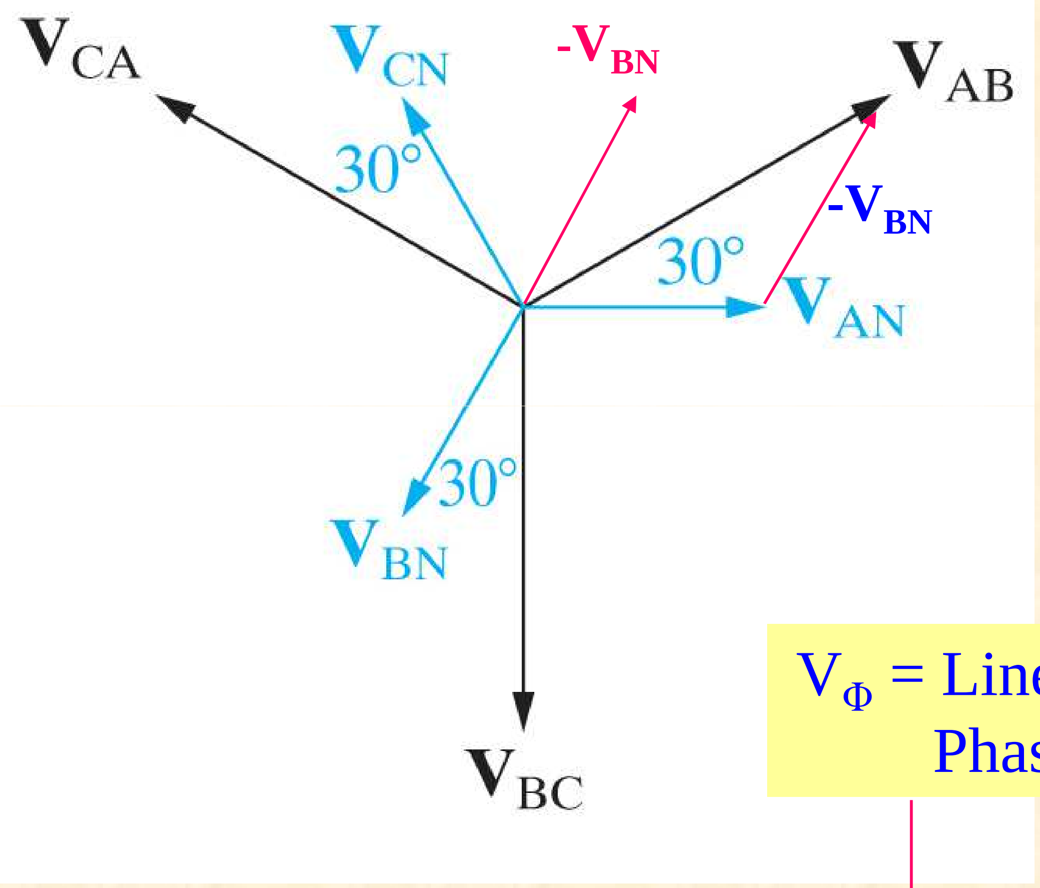
Line Voltages

$$V_{BC} = V_{BN} - V_{CN}$$

Phase Voltages

$$V_{CA} = V_{CN} - V_{AN}$$

Line and Phase Voltages for Balanced Y-connected Load



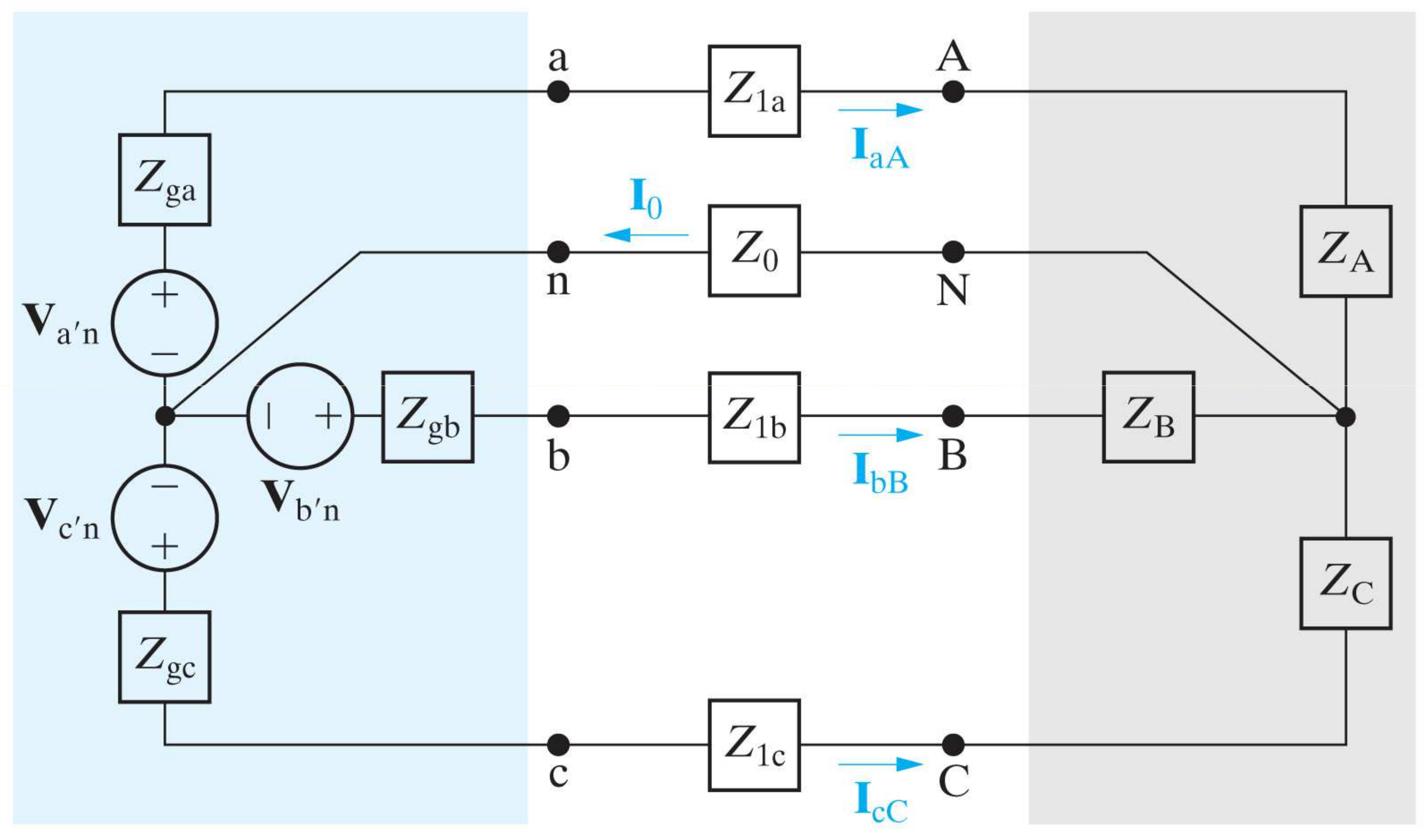
V_{Φ} = Line-to-Neutral, or Phase Voltage

$$\mathbf{V}_{AB} = \mathbf{V}_{AN} - \mathbf{V}_{BN} = \sqrt{3}\ V_{\Phi}$$

Conclusions for Balanced Y-Connected System

- The Line currents equal phase Currents
- The amplitude of the line-to-line voltage is equal to $\sqrt{3}$ times the amplitude of the phase voltage
- The line-to-line voltages form a balanced set of 3-phase voltages
- The set of line-to-line voltages **leads** the set of line-to-neutral (phase) voltages by 30° (for +ve sequence)
- The set of line-to-line voltages **lags** the set of line-to-neutral (phase) voltages by 30° (for -ve sequence)

Y-Y Three-Phase System (Four Wire)



Y-Y Three-Phase System (Four Wire)

- Z_g represents the internal generator impedance per phase
- Z_l represents the impedance of the line connecting the generator to the load
- $Z_{A,B,C}$ represents the load impedance per phase
- Z_o represents the impedance of the neutral conductor

Neutral Voltage for Y-Y System

➢Using source neutral as a reference, the Node-Voltage equation at node N can be written as:

$$\frac{\mathbf{V}_N}{Z_o} + \frac{\mathbf{V}_N - \mathbf{V}_{a'n}}{Z_A + Z_{1a} + Z_{ga}} + \frac{\mathbf{V}_N - \mathbf{V}_{b'n}}{Z_B + Z_{1b} + Z_{gb}} + \frac{\mathbf{V}_N - \mathbf{V}_{c'n}}{Z_C + Z_{1c} + Z_{gc}} = 0.$$

➢ ***For a balance three-phase system;***

✓ Three-phase voltages are balanced,

✓ **$Z_{ga} = Z_{ga} = Z_{ga}$, $Z_{la} = Z_{la} = Z_{la}$ and $Z_A = Z_B = Z_C$**

$$Z_\phi = Z_A + Z_{1a} + Z_{ga}$$

Neutral Voltage for Y-Y System

➢ **The neutral voltage can be given by:**

$$\mathbf{V}_N\left(\frac{1}{Z_\upsilon}+\frac{3}{Z_\phi}\right)=\frac{\mathbf{V}_{a'n}+\mathbf{V}_{b'n}+\mathbf{V}_{c'n}}{Z_\phi}.$$

❑ As the three-phase voltages are balanced (i.e. $\mathbf{V_{an} + V_{bn} + V_{cn} = 0}$), therefore the neutral voltage must be equals zero

$$\mathbf{V}_N = 0.$$